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REVIEW ARTICLE

Application of blockchain technology in shaping the future of food industry based on transparency and consumer trust

Vinay Singh[1,2] · Sanjeev Kumar Sharma[3]

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Abstract Food Industries, at this moment, are moving towards a new phase, and this phase will be governed by consumers and not by the industry leaders. The report shows that claims on sustainability, health, wellness, and transparency would govern the future trends in the food industry. Currently, there are several cases of misleading and false claims which hamper consumer trust. So, to uphold consumer trust, authentication of claims through transparency in the food supply chain is required, and blockchain technology can bring transparency at relatively low transaction costs. Once in a blockchain network, data is very difficult to manipulate, with no single point of authority to mess and collapse the system. Though we see mostly the financial systems using blockchain's decentralized functionality, there is a growing trend of innovative applications being built in the supply chain area for contracts and operations. With effort in the right direction and over time, blockchain will recast how operations and processes are done across the industry, including public sectors. The paper reviews the opportunity for the blockchain in enabling food industries for future-readiness, empowering the consumers in verifying the product claims and thus prevent themselves from food fraud. In doing so, the paper considers the future trends in the food industry, identifies current food fraud cases, and outlines the various applications in the agri-food chain and challenges associated with it.

✉ Vinay Singh
vinaysingh.bvp@gmail.com

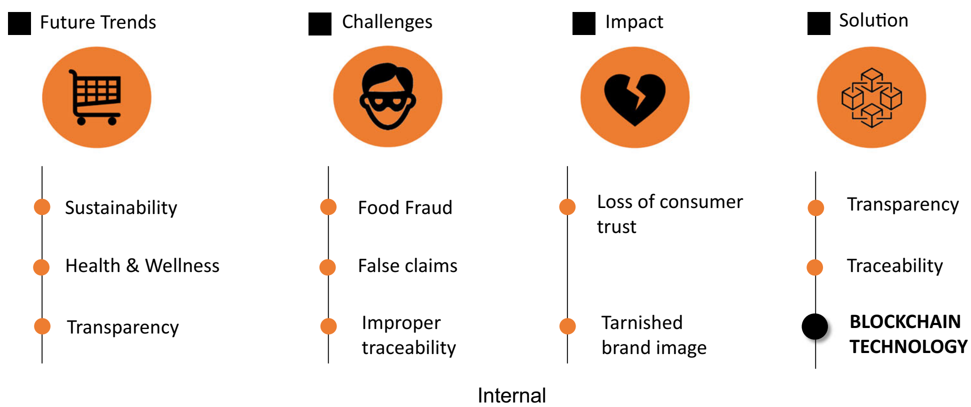
Sanjeev Kumar Sharma
sanjeevksharma.foodtech@gmail.com

1 Present Address: BASF SE, Pfalzgrafenstraße 1, 67061 Ludwigshafen am Rhein, Germany

2 Department of Business Administration, National Central University, No. 300, Zhongda Road, Zhongli District, Taoyuan City 320, Taiwan

3 Chocolate Productivity[AMEA], Mondelez India, Mumbai, Maharashtra, India

Graphical abstract



Keywords Consumer trust · Food fraud · Transparency · Blockchain · Food supply chain · Food trends

Introduction

Several trends are likely to have an impact on the future of the food industry. Technology, convenience, and personalization are some of the top trends. However, it will increasingly revolve around technology to address the need for convenience (Amentae 2021). Various factors influence the way the world produces, distributes, buys, sells, and consumes food. Surveys and reports conclude that transparency (as high as 90% (Research 2021) will be one of the key non-price purchase triggers. The global food traceability market size was valued at $10.96 billion in 2017 and is expected to reach $22.3 billion by 2025, registering a CAGR of 9.3% from 2018 to 2025.

The food supply chain is a complex system involving several stakeholders and multiple intermediate processes (Hassoun et al., 2020; Leng et al., 2018), which could create information asymmetry and possible loss of information during the transition. This has resulted in several cases related to false claims made by packed food companies, bringing economic loss, and impacting consumer trust to a large extent.

Blockchain's robust and decentralized functionality can be used to tackle food fraud and security (Sharma and Singh, 2021). A blockchain is a digital transaction ledger deployed over a computer network without dependencies on a trusted third party (Sanka et al. 2021). It comprises blocks of data that are immutable, containing a list of transactions and a unique pointer to its predecessor blocks. Blockchain is interchangeably referred to as distributed ledger, a specialized form of a distributed database (Addison, 2019).It assigns unique digital identifiers to food products, making these products easily traceable throughout the supply chain, containing data like the batch number and expiry dates. With this, we can make a food ledger and transactions register that will potentially avoid fraud and enable sourcing information to identify the foodborne illness. It would be the next step in promoting on-farm data sharing (Kawaguchi 2019; Mutuko 2018).

In our work, we consider the application of blockchain in increasing consumer confidence in the food industry by improving food fraud and traceability. The paper in hand explores the opportunity for the blockchain in empowering the consumers in verifying the product claims and thus preventing them from food fraud. In doing so, the paper considers the future trends in the food industry, identifies current food fraud cases, and outlines the various applications in the agri-food chain and its challenges. The paper concludes by highlighting how blockchain technology can potentially reduce food fraud and data tampering risks, with recommendations for future research and development.

This paper is structured as follows. Section 2 provides a review of blockchain technology. Section 3 then describes the Future Trends in the Food Industry. We investigate details of various applications of blockchain in the Food Industry in Sect. 4. We take the case study of IBM and Wal-Mart's collaboration for food fraud preventions and discuss Wal-Mart's benefits of using blockchain technology in their food supply chain. We further discuss the current limitation of Blockchain Technology in Sect. 6. The paper concludes with a discussion on our findings and directions for further research.

Background

Consumer trust and the importance of blockchain

Consumer trust forms the basis of loyalty, commitment, product acceptance, and good long-term relationships with brands (Wu et al. 2021). Transparency (David et al 2022) is also related to trust-building, as explicit protection measures of consumers' data (Wu et al. 2021), production transparency, labour conditions, and social responsibility (Sharma and Singh 2021) reinforce trust. On the other hand, a centralized data system can harm users' trust and confidences (Moura and Gomes 2017) as the central entity can be a single point of failure.

Blockchain trust-free distributed network of nodes and tamper resistance characteristics can support consumer trust (Garaus et al. 2021). The trust by design feature of BC is analysed in the context of supply chain management by Imeri et al. (2019) propose a classification of BC applications based on a literature review of 260 articles and 54 reports. Their analysis classifies BC applications in business and industry, data management, financial, integrity verification, governance, Internet of Things (IoT), health, education, privacy, and security.

Tracking for compliance with blockchain framework

Aung and Chang (2014) conclude that to enhance transparency and compliance, the first step is to identify what factors are directly associated with compliance and quality. In the implementation stage, blockchain has the design needed to track the identified factors which enhance transparency and to ensure that the system can automatically collect and store the desired data in an immutable form (Kamilaris and Prenafeta-Boldó 2019). Identifying the right tools and the appropriate incentives for key stakeholders joining this effort is important in streamlining the data transaction stage (Liu et al., 2021).

2.3 Bridging technology and knowledge gaps among stakeholders along the value chain

The existing technology gap between stakeholders needs to be addressed when implementing blockchain technology in food supply chain (Kamble et al. 2019; Köhler and Pizzol 2020). The technology gap needs to be investigated and the question of whether the organizations involved have the capability to adopt the system must be considered (Kramer et al. 2021; Amentae 2021; Leng et al. 2018). Large corporations can face interoperability challenges since they have established mature technology infrastructures which requires significant efforts to adapt. Small and medium sized enterprises need to address the challenge of a lack of resources and the capacity to adopt new technologies (Liu et al. 2021).

Designing for data privacy and future scalability

Scalability, security, and decentralization are competing forces in the "blockchain trilemma" (Sanka et al. 2021; Zhu et al. 2018). Some of the main impediments for enterprises taking part in a blockchain consortium are concerns about data privacy. From a technology perspective, one of the main constraints when implementing a blockchain consortium is the ability to cope with the increased number of transactions (e.g., required storage capacities and resources). This is especially the case when a blockchain system is deployed with other data-intensive infrastructure such as the "Internet of Things," which automatically collects data (Sharma and Singh 2021; Kamble et al. 2019). Therefore, managing scalability is the key to ensuring a successfully running system.

Governance and ecosystem enablers

The blockchain governance model determines the operational and business rules, thus guiding the activities of the network. Blockchain governance can be determined by an individual, a group of people or all the users within the network based on how decentralized the technology architecture is (Park and Li 2021). In a country's food supply chain ecosystem, the enablers are the government, NGOs, technology suppliers, private sectors, and small and medium sized enterprises. Designing a blockchain governance system that motivates the enablers to integrate it in running systems and that is beneficial to all the enablers is key and is a challenge.

Limitation of current approaches

To the best of our knowledge, none of the published papers address the analysis of the relation between BC technology and consumer trust and transparency in the food industry context. The work of Hawlitschek et al. (2018) is the most closely related to ours. However, they analyze BC technology and trust specifically in the sharing economy. Similarly, DaSilva, and Moro (2021), also try to understand trust in BC from the marketing perspective. And Garaus et al. (2021)) in their work, study how blockchain-based traceability will impact the retailer's choices.

Material and methods

Materials used in the analysis come from three sources– literature review (see Appendix A), Expert Interview(See Appendix B), and collection of use cases and applications as deployed in Food business ventures and developed and tested in selected research projects. The Flow chart of review Methodology is available in Appendix C.

Literature review

The searches were made on the Scopus database using four alternative keyword combinations:

- (Agriculture* AND food AND supply AND chain AND management) AND PUBYEAR > 2017) AND (Blockchain*),
- (Food AND fraud AND traceability AND Transparency) AND PUBYEAR > 2017 AND (Blockchain*),
- (Fraud AND supply AND chain AND management AND PUBYEAR > 2017 AND (Blockchain*),
- (Traceability AND supply AND chain AND management AND PUBYEAR > 2017 AND (Blockchain*),

These keyword combinations yielded 286 hits between January 2017 and November 2021. Following a closer examination of the contents of abstracts, conclusion and methodology 74 materials, including articles, papers, and reports, were selected as highly relevant for analyzing our topic.

Expert interview

We interviewed 32 experts from Germany, India, Ireland, Taiwan, Malaysia, and Singapore. Feedback and comment were collected via interview questions. This would help us to focus the specific topic within the research scope. Sample questions and answers can be seen in Appendix B.

Case study

Furthermore, since important research and development activities in this field are carried out by companies involved directly in the agri-food operations, the review also took account of major technological products and digital applications used in the agri-food chain. This help us to assure that our research was in direction of where industrial aspiration are.

Future trends in the food industry

When we look at the global consumer trend, environment friendly and sustainability, wellbeing, value for money, individualism, technology, and experience will dominate the next decade of the consumer market. The trend in the food and beverage industry won't be different. Consumers are graduating from "me" to "us." They are becoming equally sensitive to personal health and environmental health. While the mass-market and 'one-size-fits-all' approach will still have value, there will be an increase in demand for personalization. Mintel's Global Food and Drink Trends 2030 (Mintel 2019) predicts a similar trend as well. As per Mintel's report following trends in the food and beverage industry will decide the market leader:

a. The success of the company and brands will be based on how they take care of the health of the planet and its population. Consumers will look for food that will give holistic personal development and positively impact the environment.
b. Highly customized or hyper-individualized food with an approach to physical and mental health. Consumers are ready to share their personal information if companies can provide them customized nutrition.
c. Consumer trust in food science and technology will strengthen, and thus the demand for a science-based solution like lab-grown foods, organic foods, and vertical gardens will be the trend in the industry.

If we investigate the new launches in the last two decades, we can see several claims in almost all the food industry categories. To have a reference, we have compiled some of the critical claims associated with new product launches since 2000 (Table 1) as below:

Label Insight report 2018 (Food Marketing Institute 2018) on transparency strongly advocates the need for transparency in the future, and it provides guidance for industry. The summary of the guideline given in the report can be clubbed into the following points:

- Embrace transparency to build consumer trust and boost loyalty. It will be a critical factor for new-age consumers who are educated, informed, and don't shy away from spending more.
- Consumers are looking for more information, and they are not only restricted to the ingredient list. In addition, consumers expect that the manufacturers provide information related to side effects, allergens, quality standards, and storage.
- The report also foresees that consumers will keep increasing the bar of transparency, may shift to other brands providing more comprehensive information. So, tracking these consumer's shifts and making quick

Table 1 Critical claims associated with new product launch (2000–2019). Data source Mintel GNPD

Claims	Europe	Asia Pacific	North America	Latin America	Middle East and Africa	Total
No additives/ preservatives	103	82	37	19	14	255
Low/No/ reduced allergen	79	19	34	53	5	190
Environment friendly package	81	34	29	26	9	179
Gluten free	64	15	30	51	4	163
Organic	104	19	31	6	3	162
Vegetarian	61	83	5	1	8	158
Kosher	12	11	69	15	14	121
Ethical–recycling	53	23	19	17	7	120
Low/no/reduced fat	45	20	24	13	5	106
Halal	6	61	1	1	17	87
Total sample	420	274	163	122	56	1,035

[#] *All numbers are in '000)*

adjustments and strategic shifts would be imperative for business.

Transparency will be of high value, primarily when claims are related to sustainability and the environment (Mol 2015). Customers' demands for transparency have grown considerably in recent years. There is a common thread between the future trends in the food and beverage industry as reported by Mintel and Label Insight report 2018 (Food Marketing Institute 2018)–and it is "consumer trust." To build this consumer trust, food manufacturers must innovate products that will cater to consumers' future needs and innovate processes to ensure that they believe in their products. To believe in the product, consumers would need more and more authentic information about the product and to disseminate this information.

Food frauds and its impact on consumer trust

Consumers who buy products are entirely relying on the claims made by the brand or manufacture. One-third of U.S. consumers rank trust as a top-three purchase driver. 6 in 10 consumers are not ready to buy products and services from companies they do not trust. However, there are several cases where these claims are false, and consumers are deceived.

As per the U.S. Food and Drug Administration (USFDA), food fraud or "economically motivated adulteration" is "fraudulent, intentional substitution or addition of a substance in a product to increase the apparent value of the product or reduce the cost of its production, i.e., for economic gain. In addition, the European Medicines Agency includes dilution of products with increased quantities of an already-present substance to the extent that such dilution poses a known or possible health risk to consumers and the addition or substitution of substances to mask dilution (Johnson 2014).

As per the European Commission, "food fraud is about intentional actions taken by businesses or individuals to deceive purchasers and gain undue advantage from there, in violation of the E.U. agri-food chain legislation. These intentional infringements may also constitute a risk to human, animal or plant health, or animal welfare or the environment as regards GMOs and plant protection products."

The globalization of resources has increased the inter-continent movement of foods exponentially. This has resulted in the establishment of complex globalized food supply chains, which enabled access to any food material to consumers across the globe. An increase in market demand and the economic motivation to provide cheaper food products have contributed to the prevalence of food fraud. Companies rely on false claims about the product to have a more competitive advantage, thus deceiving the consumers. Food frauds lead to economic losses to the consumers and lead to serious public health risks.

Our study here has reviewed the different types of food frauds registered with the E.U. Food Fraud Network. These frauds can be broadly categorized into the following bundles:

1. Mislabelling: When the products are sold, intentionally put wrong information or claim on the pack, which may deceive consumers. E.g., in 2018, the case was registered with E.U., where olive oil from Spain was intentionally mislabeled as extra virgin olive oil and sold to the consumers of the U.K (Charlebois 2020).
2. False documentation: In such cases, either required documents about the product information are absent, or

data are manipulated. E.g., in 2019, Italian Tomato was sold as Piennolo (an Italian PDO) that lacked the proper certificates to prove their geographic origin. There can be cases of data manipulation or false declaration of origin to evade taxes/tariffs, e.g., U.S. imports of catfish from Vietnam labeled as grouper to avoid anti-dumping duties(Jurica et al. 2021).

3. IPR infringement: I.P. infringement is any breach of intellectual property rights. For example, imitating genuine goods, also called. "counterfeiting," to take advantage of the superiolue of the imitated product.
4. Improper ingredients: This included addition, removal, or replacement of ingredients for economic benefit (Du and Pan 2019)

- *Replacement:* here, the costlier and valuable authentic ingredients are replaced or partially exchanged with low-quality or less expensive substitutes. An example could be increasing the apparent protein content of milk by adding melamine.
- *Addition:* In this manufacturer adds small amounts of an unapproved ingredient to mask inferior quality ingredients. E.g., the addition of prohibited Sudan Red dyes to improve the color of poor quality paprika.
- *Removal:* In this manufacturer intentionally removes authentic and valuable constituents without declaring them on the label. E.g., manufacturing poor-quality honey by filtering out pollen or another residue from the beehive. This makes it difficult to trace the honey's botanical and geographic origin.
- *Using an unapproved process:* These cases include where the food is manufactured by an unapproved process or the food has gone through unapproved treatment. E.g., food manufactured through the process is not approved under Halal requirements.

Annual reports of the European Union Food Fraud Network and the system for Administrative Assistance have an overview of various types of frauds observed in the food industry. Figure 1 provides an overview of various food frauds mentioned in the 2018 report of the European Union Food Fraud Network (European Commission 2018).

The cases of food fraud are neither new and nor restricted EU region. We have had several occurrences reported in the past. Below (Table 2) are some of the reported cases of food fraud in different categories of claims. Cases of food fraud are reported globally and have been rising irrespective of the significant amount of development and technological implementation in detection and preventative measures across the food supply chain (Visciano et al. 2021; Ruth and Huisman 2017).

Some of the recent cases include maple syrup being diluted with low-quality sugar (Ahmed and Broek 2017), repackaging rice with new expiry dates (Mutuko 2018), and mixing groundnuts with stones and gravel (European Commission 2018). In addition, according to a report recently published in Brazil, 45 out of the 140 brands of olive oil surveyed did not correspond to the indications given on the labels. Not only this, but some of them also have an ingredient ("lampante") that is not fit for human consumption (Olive Oil Time 2017).

Everstine et al. (2013) bring forth the need for a holistic and systematic approach to mitigate food fraud. In their recommendation, they argue for a risk assessment technique and insist on using historical data sources. A similar finding is reported by Visciano et al. (2021), where they discuss various global incidents and misleading situations. Bouzembrak and Marvin (2016) mention four elements of food chain integrity: product integrity, process integrity, people integrity, and data integrity.

Esteki et al. (2019) recommend a holistic approach to develop and implementing food integrity management systems. They mention that in the past 20 to 30 years, a highly complex food system has been established. Due to this safeguarding, food integrity should be the responsibility of all stakeholders in the supply chain. Table 3 below shows Types of food fraud that can be controlled at different stages of the food supply chain. It can be noted that, to date, research is focused on analytical methods to detect food fraud. One can find several publications and reviews on analytical techniques on both targeted (i.e., where the compound of interest is known) and nontargeted methods (e.g., screening) have been published (Abbas et al. 2018).

As food fraud has directly impacted consumer trust, it has brought attention and interest back in consumer studies. Extensive and large-scale studies in the food industry have been conducted on attitudes and perceptions towards food fraud and consumers' confidence in Bangladesh (Nasreen and Ahmed 2014), China (Wu et al. 2021; El Benni 2019), the UK, and EU (Barnett et al. 2016; Charlebois et al. 2016)). Industry partners have also been stepping up their development, and companies like IBM have come up with solutions. For example, IBM Food Trust uses the blockchain solution to build transparency across the supply chain engaging all the stakeholders, which includes farmer, processor, retailer, and the consumer. The solution provides participants with a permission-based, shared view of food ecosystem information (IBM Food Trust 2020). With such solutions, it is convenient to publish data and share information in a controlled way. In the case of a solution from IBM, the Tool user in real-time can search and identify food products based on product name sorted by dates. It also facilitates the user community to use smart contracts in a private channel which can be used between

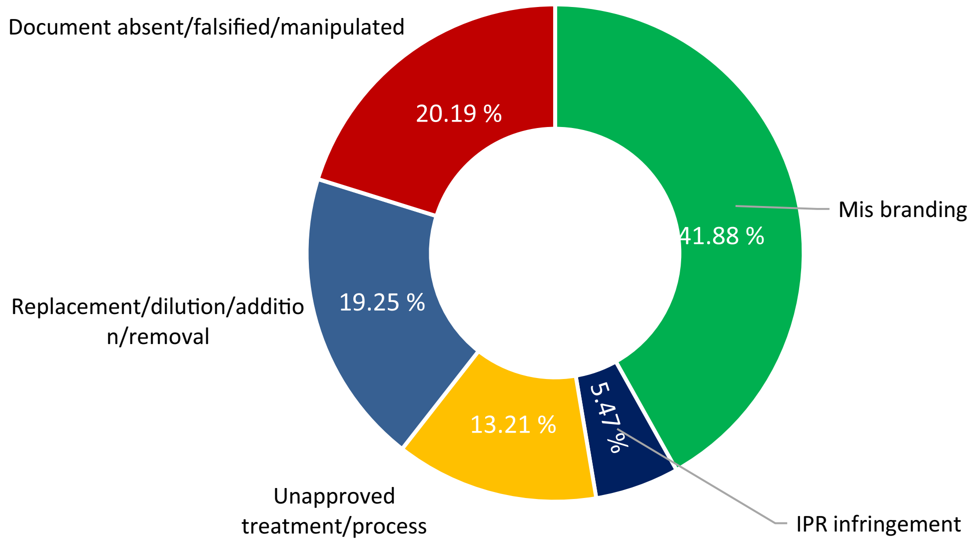


Fig. 1 The type of suspected violations reported in the AAC-FF** in 2018

Table 2 Food fraud in different categories of claims

Year	Country	Food fraud category	Example
1981	Spain	Mislabeling	"Rapeseed oil" fraud intended for industrial use was sold as olive oil
1998	India	Addition of unapproved ingredient	The mustard oil was deliberately adulterated with poisonous *Argemone mexicana* seed oil
1999	Belgium	Unapproved manufacturing process	Dioxin came in food chain via contaminated animal fat used in animal feeds
2008	China	Addition of unapproved ingredient	Milk adulteration with melamine resulting in more than 50,000 sick babies and six fatalities
2013	UK	Mislabeling	The horse meat was added to beef products up to 100%
2014	Costa Rica	Improper manufacturing process	Alcohol contaminated with methanol due to improper manufacturing
2018	Bangladesh	Addition of unapproved ingredient	Producing juices that did not contain any fruits and were manufactured with hazardous chemical substances
2018	Britain	Mislabeling	Selling meat labelled as the "Best of British" when actually it was sourced from abroad
2019	Brazil	Mislabeling	Olive oil brands were having undeclared soya oil and oils of unknown origin
2019	Italy	Mislabeling	Selling eggs labelled "organic" that were produced by hens kept in cages
2019	Italy	Document absent	Italian Tomato were sold as Piennolo (an Italian PDO) that lacked the right certificates to prove their geographic origin
2019	Argentina	Mislabeling	Extra virgin olive oil contained oils other than olive oil
2019	Netherland	Mislabeling	Selling eggs contaminated with fipronil and with a false claim that the eggs originated from a farm that produced "free range" eggs
2020	Italy	Addition of unapproved ingredient and Mislabeling	Low cost wine was sold as a quality product for a higher price, in some cases with claim of being organic
2020	Brazil	Mislabeling and addition of unapproved ingredient	Olive oil contained 85% soy oil and 15% "lampante", which is not apt for human consumption

two or more specific network members. As the data on the channel is unencrypted, it allows automated decision-making. IBM Food Trust has been successful in harnessing the core functions of blockchain in the food supply chain.

Blockchain technology

A blockchain is a digital transaction ledger, also referred to as distributed ledger technology, based on peer-to-peer topology. It allows data to be stored and access globally on multiple servers (Liu et al. 2021; Kramer et al. 2021). It

Table 3 Types of food fraud which can be controlled at different stages of food supply chain

Fraud category	Different forms of frauds	Supply chain stage as a source of data	Data captured by IoT and secured by blockchain
Document falsification and data manipulation	a. Absence of document b. Data manipulation	All the stages	Documents and data detail captured and stored. These documents and data cannot be manipulated and if made available, can be easily accessed by consumers and regulating agencies at any point of time by scanning the code on product pack
Misbranding	a. False claim on origin of product b. False claim of organic c. False claim of vegetarian and vegan	a. Sourcing of raw material b. Processing	
Adulteration	a. Addition of unapproved / undeclared ingredient b. Addition of cheaper ingredient	a. Sourcing of raw material b. Processing	
Unapproved process	a. Not adhering to food safety norms b. Not adhering to Halal process while claiming to be Halal	a. Sourcing of raw material b. Processing	

comprises blocks of immutable data, containing a list of transactions and a unique pointer to its predecessor blocks (Yiyan et al. 2020). These blocks (data files) can be transmitted and processed via software platforms, allowing storing, and representing these data blocks into human-readable forms (Kramer et al. 2021; Alkahtani et al. 2021). To understand Blockchain, Let's revisit few terminologies widely used.

- *Node*: they are the blockchain infrastructure, i.e., every computer in the network is called a node, which stores a copy of the Blockchain. The nodes synchronously exchange the latest blockchain data, so all nodes are updated and consistent (song et al. 2020; Kramer et al. 2021).
- *Decentralized*: This is the underlying technology on which the whole idea of Blockchain is based. There is no single server where the entire information is stored. Rather, it is saved as copies in several computers across the network, making it a robust system as even if a computer is crashed, the whole system will still be up (Song et al. 2020; Kramer et al. 2021).
- *Trustless:* It should not be interpreted as "not trustworthy." In contrast, Blockchain is a very trusted system. However, as the whole system is running transparently, the system is open source, and there is no need for trust among the parties involved in every node, and any node can never cheat other nodes (Tonkin et al. 2020).
- *Collectively Maintain:* All the information stored in blocks of the system is collectively maintained by all the nodes in the whole system. Anyone can become one of these system nodes after registering online (for sure once approved by other parties involved).
- *Reliable Database*: The System ensures that every node has a complete copy of the database in the form of a sub-database. This makes it impossible to Tamper database from one node as one would need at least 51% control of the nodes in the whole system at the same time. Blockchain thrives on having more nodes; more nodes in the system will make it more secure.
- *Anonymity:* In the blockchain system, the identity of each node is anonymous.
- *Mining process:* Each node in the system is also known as "miners." The nodes verify each new transaction before being added to the Blockchain. This process is called the mining process. It is also called a voting process as miners add new blocks on the chain or new transactions on the block by a consensus algorithm, which must be confirmed by most of all the nodes in the system, like a voting operation, as the valid data.

Blockchain uses digital signatures and cryptographic hash functions to protect each block on which transactions are stored. Third-party verification is discounted in blockchain because the process is decentralized and performed by the nodes connected to each block. Each user on the blockchain is provided with a public key and a private key which the user must use to create a valid digital signature (Kamilaris et al. 2019).

Table 4 Different blockchain technology-based programs currently run by some of the food industries

Year	IT solution provider	Companies using/working on block chain technology program	Program objective
2017	IBM	Dole, Driscoll's, Golden State Foods, Kroger, McCormick & Co., McLane Company, Nestlé, Tyson Foods, Unilever, and Walmart	A blockchain collaboration with the intention of strengthening consumer confidence in the global food supply
2018	IBM	WalMart	Food traceability system using blockchain for leafy green vegetables supply chain
2019	IBM	United States seafood trade association National Fisheries Institute (NFI)	To track multiple seafood species jointly pursued by multiple companies
2019	IBM	Nestlé and French retail giant Carrefour	Track the supply chain of Mousline (instant mashed potatoes brand) from its source through the journey to the consumers
2019	OpenSc	World Wildlife Fund-Australia (WWF-Australia) and global corporate venture BCG Digital Ventures (BCGDV)	To allow both businesses to track products they produce, as well as consumers to view the origins
2019	OpenSc	Nestlé	To trace milk from farms and producers in New Zealand to the firm's factories and warehouses in the Middle East
2019	E&Y	Big four audit firm E&Y	To help consumers across Asia determine the quality, provenance and authenticity of imported European wines
2019	SAP	Bumble Bee Foods	For seafood traceability
2019	Microsoft Azure	Starbucks	To track the production of coffee and allegedly provide coffee farmers from Rwanda, Colombia and Costa Rica with more financial independence
2019	VeChain	Walmart China	To track food through its supply chain
2019	Microsoft Azure	Bühler	Block chain tool to reduce microbial contamination in dry goods

Before addition to the chain of blocks (information), this block is verified by thousands, perhaps millions, of computers distributed around the blockchain network. Once added to the chain, the block is stored as multiple copies across the net, which creates a unique record with a unique history. Modifying a single record is impossible as it needs to modify the entire chain stored in millions of computers (nodes) (NFM 2021). The immutability of blockchain is due to the cryptographic (coded) hash function. A slight change in input changes the hash completely.

A blockchain should be universal and can be adapted to specific situations. It has been seen that the parties involved in a transaction come under pressure when asked to use a given type of blockchain. This can act as an effective blocker when we see colossal innovation and progress in blockchain technology, and there is vast unpredictability for the best choice for the future. Another disadvantage of blockchain technology is that it has not seen a homogenous implementation across the supply chain (Ruth and Huisman, 2017). This implies various stockholders are still on a different platform and are not fully motivated to implement and use blockchain. It would require a strong push among the community, including close collaboration and system integration to operate smoothly.

Application of blockchain in the food industry

Blockchain guarantees a single version of the truth in a trustless environment across various entities or agents with access to this decentralized ledger (Rana et al 2021). This secured environment provided by Blockchain can be utilized in the food industry supply chain for ensuring traceability and transparency at the consumer end. Implementation in the food industry must be coupled with the correct data capturing systems (Internet-of-things) and certified and authorized external agencies (Sharma and Singh 2021).

In the packed food industry, claims and transparency can benefit a lot by using blockchain. It promises improved regulatory compliance, increases speed in transactions and local and international exchanges, and digitizes assets for ease of trade, especially in the packed food industry where the seed would come from one continent. The final consumer would be in another. Table 4 shows different blockchain technology-based programs currently run by few food industries.

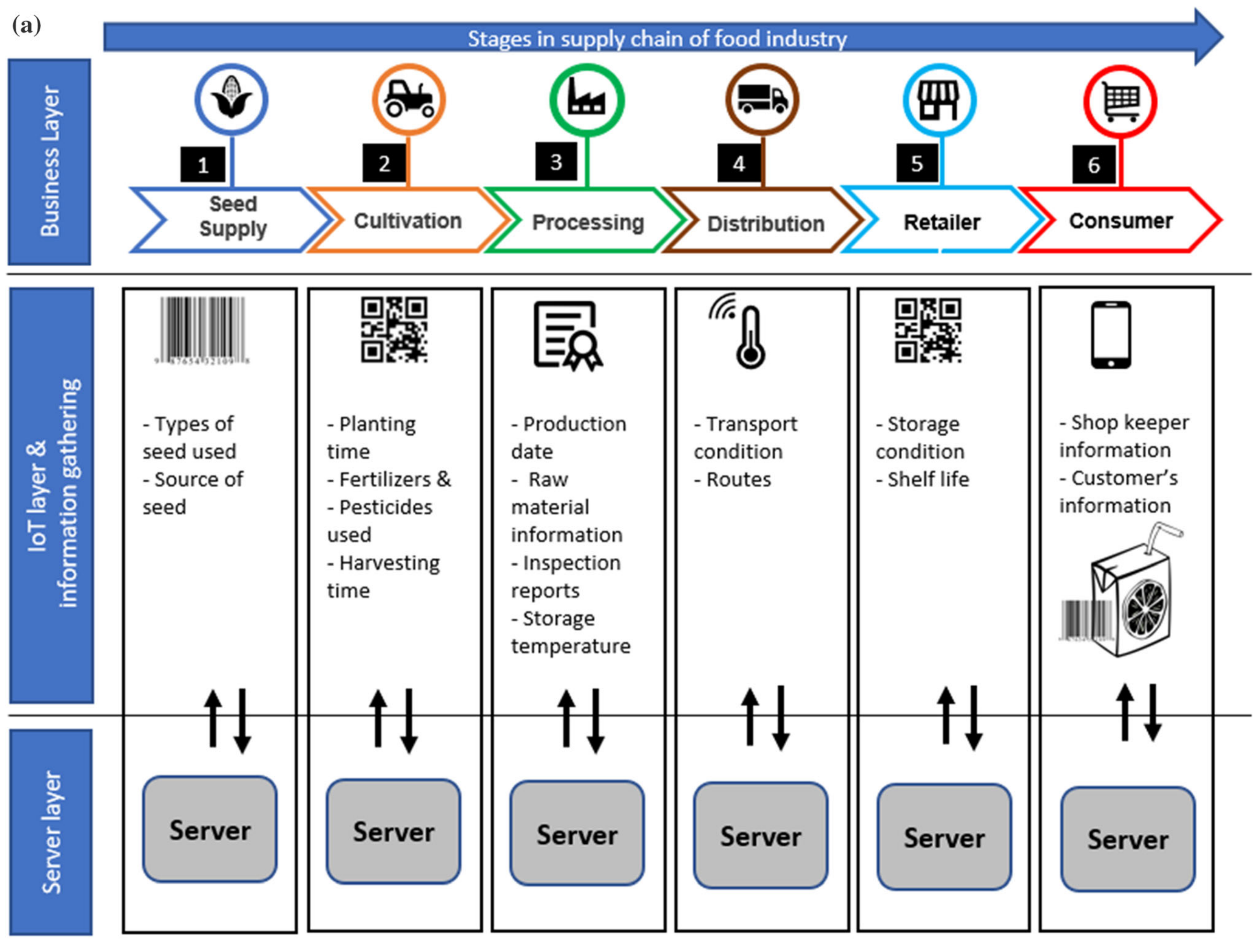


Fig. 2 A simplified Food Supply chain system and data gathering at every stage. In current system **A**, the data captured at every stage sits in silo and the consumers can not the access entire product history. **B** With blockchains data captured at every stage will be stored in a shared database which can be accessed by consumers through mobile app. (adopted from Kamilaris et al. 2019 and Aung and Chang,2014)

Digitization of the food supply chain

The complexity of the food Supply chain makes it a challenging task to track and identify food products and processes along the supply chain. The food industry considers traceability as a new quality index (Caro et al. 2018). Regulations are being imposed to enable tracking and identifying all raw materials used in food products. With the advent of technologies like the Internet of Things (IoT), it is possible now to get real-time information about products and cases of fraud across the supply chain, including production and distribution (Sharma and Singh 2021; Zhu et al. 2018). Such technologies address practical problems/monetary constraints and (re)design/optimize food supply networks (Zhu et al. 2018).

Though several published research papers have discussed traceability applications in food supply chain management (Badia et al. 2015; Yan et al. 2018), none have analysed real-time usage of Blockchain's track and trace capability item-level. Similarly, one can also find several research papers showing the advantages of Blockchain in ensuring food safety through faster traceability, in controlling food frauds but in isolation. In this paper, the authors have tried to bring the pieces together—the entire scenario of food fraud and the relevant information about the problem statement.

The food supply chain is a multi-actor distributed supply chain, has, in most cases, products of agriculture as input, and the consumer is the final client, as we call it, to the farm to fork. This necessarily means that Agriculture and food supply chains are well interlinked (Rana et al. 2021). There are shreds of evidence that blockchain applications became used in supply chain management soon after the technology appeared (Potts 2019). Blockchain in supply chain management will see an exceptional growth of

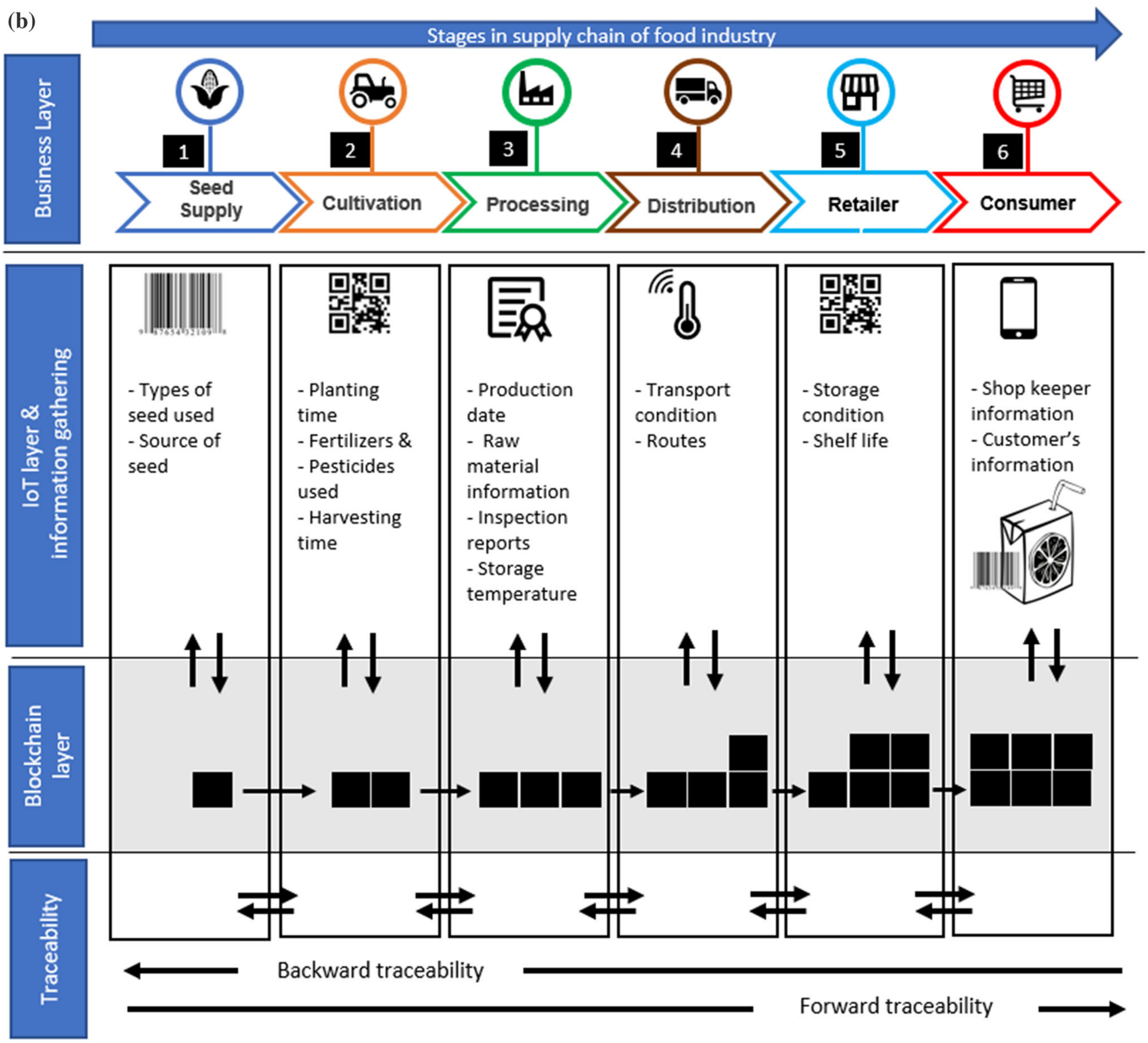


Fig. 2 continued

around 87% and increase its foothold from $45 million in 2018 to $3314.6 million by 2023 (Tribis et al. 2018).

The food supply chain consists of various players, we tried to map physical flow in the food industry to the digital flow and see how we can track it via blockchain. As shown in Fig. 2A, broadly, the physical flow can be categorized into–seed supply, cultivation process, processing, distribution, stock at the retailer, and pick up by consumers. For these six steps, we can create a digital flow layer as a middle layer using QR codes, RFID, online certificates, mobile phones, sensors, etc., depending on which step we are. Internet/web services act as a connecting platform. As shown in Fig. 2A, in the current system, every stage sits in a silo, and the consumers cannot access the entire product history. Whenever consumers pick up a pack of food, they are unaware of the route traversed by the food present in the pack. They are mainly exposed to the label information, and the rest rely on the manufacturer. Through blockchain technology (Fig. 2B), data captured at every stage will be stored in a shared database that can be accessed by any stakeholders in the entire chain and even by the consumers through the mobile app. At the blockchain network level, each interaction captured is authenticated and confirmed by the business partners of the food supply network. Thereby bringing transparency and consensus between all stakeholders. A block is only added to the chain of blocks after being validated. Once validated, it becomes part of a

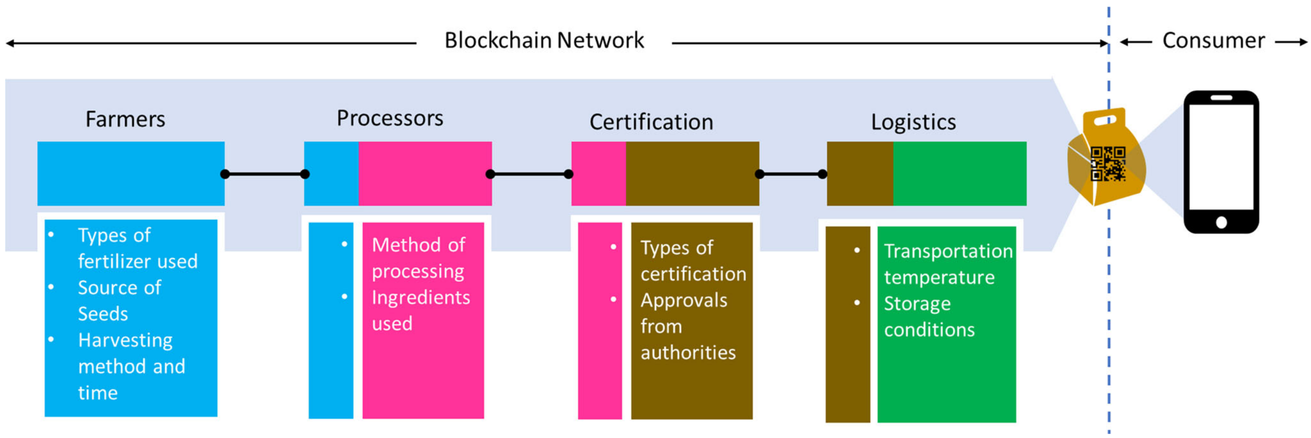


Fig. 3 Pictorial depiction of information forming blocks (adopted from NFD 2021)

permanent record of the entire process (Chang and Iakovou 2019).

Bringing transparency and building consumer trust

In the hyper-connected and ever-evolving world, transparency is a new power. We saw that "claims" have been a centre stage for positioning new products in the last two decades. In the future, we will see similar trends but with some new claims like the claim to be personalized, the claim to be organic and ethical, etc. If everyone will come out with some or another claim, then there would be a requirement of a differentiator. We also noticed that while many companies are thriving on attractive and authentic claims, many rely on false claims. In such a case, transparency is going to rule the future of the food industry. The companies that will be more transparent about their products would sustain consumer trust and thus would be coming out as a leader in this complex world of authentic and fraudulent claims. Companies that would make product information more accessible to consumers will dominate the industry. Few business leaders have long realized the competitive advantage of open and transparent supply chains. For example, fish suppliers John West increased their sales by £17 m by empowering their consumers to trace their canned tuna back to the fisherman. They did it by including codes on their tuna cans.

We sometimes use traceability and transparency interchangeably, but there is a slight difference. Traceability aims to answer the 'what/when/where questions of inventory transfer in supply chains, whereas transparency, tries to bring the 'how' aspect. For example, if we would like to know about the history of cornflakes served in your breakfast bowl, through the traceability principle, we can reach up to the farm where the corn was grown. However, transparency will provide information about where the seeds were sourced, how it was cultivated by a farmer (organic or inorganic), how was it harvested, and handled while being transported. The transparent operation will be a key pillar in facilitating can environmental sustainability and social responsibility (Mol 2015).

Pournader et al. (2020), proposed the interlinked relationship between Trust, Technology, Trade, and Traceability which is now possible with the emergence of blockchain. Generally, it is concluded by many authors, including Pournader et al. (2020), that the technological aspect of blockchain will bring desired impact and benefits to trade operations by bringing Traceability, Trust, and Transparency to the system.

Current researches show that blockchain technology would provide this trusted digital environment. With a centralized system, once the transaction (information) has been recorded into a blockchain, it cannot be changed or manipulated. To manipulate data in the blockchain, one will have to change the entire history of it, as data are chronologically stored and verified. In the blockchain, each block (information/input) is linked to another block that contains data and a hash of the data inside the previous block. So, any change in data at any stage/block will change the hash drastically, therefore causing an avalanche effect disturbing the entire blockchain thus secures the data from any fudging (Fig. 3).

The only catch is the information captured be accurate and reliable. Blockchains enable end-to-end traceability by bringing a common technological language to the food chain while allowing consumers to access the story of foods on their labels through their phones. Thus, the future of the food industry will be based on the "business of claims," "transparency" will be the soul of these claims, and "blockchain technology" will enable this future trend of transparency. With blockchain technology, a secure and distributed way to perform transactions can be achieved among different trusted parties.

There have been several efforts to create a centralized data repository that acts as a single source of truth. However, despite various measures, the entire product history remains inaccessible mainly and difficult to verify. Moreover, as this information sit at different locations and is controlled by several parties, data become more vulnerable to fraud. To have a transparent system, many companies rely on neutral, not-for-profit, governmental entities for creating a centralized data storage to ensure a flow of trusted information. It would be challenging to neglect the bias, vulnerability to bribery, or targeted hacking in a practical scenario and rely on a single party to establish a reliable and authentic data repository (Provenance, 2020). This is where blockchain technology comes and provides unparalleled transparency through neutrality, reliability, and security. Using blockchain, we can securely audit all transactions and inspect the uninterrupted chain of custody from the raw materials to the end sale (Provenance, 2020).

Case study—IBM and Wal-Mart food trust

We undertook the case of IBM's collaboration with Wal-Mart to evaluate whether blockchain technology food fraud cases can be detected or reduced. The traditional approach requires a lot of resources and time to find the sources and routes of food with safety issues (Köhler and Pizzol 2020). Humankind had seen various disease outbreaks like Escherichia coli due to hazardous food. Wal-Mart, too, suffered a considerable food scandal with milk and infant formula across China. It was estimated to negatively affect over 300,000 people. Due to many suppliers, customers, workforce, and documentations, it took several days to identify the origin of products. But this led to consensus at Wal-Mart that better traceability is required in their supply chain. They started a pilot project with the IBM Food Trust program to track Mangoes and Pork products (Kshetri 2018). With blockchain, they can track pork production from pork farms to the Wal-Mart stores in china and ensure food safety. In 2017 in the Wal-Mart Global Responsibility Report, they also discuss the monitoring of Mangoes coming from Latin America to the United States (Kshetri, 2018). They track in real-time information like origin (food), batch number, Plant, processing data, and transportation details at each step of delivering food from suppliers to a consumer. This has tremendously reduced the tracking to obtain the original records for Wal-Mart. For example, in the past, it would take six days (paper-based tracking system) for Wal-Mart to track mangos from Mexico, but with blockchain, it takes 2.2 s (Kshetri 2018; reference, Walmart's).

Limitation of blockchain technology

While most organizations lack an organized ecosystem and platform for scaling up blockchain applications, many fundamental issues need to be addressed—starting with resources. It is not so easy to find people with technical know-how(Galvez et al. 2018). Data governance and privacy is still an open topic and needs to be addressed. Another big challenge is the immutability property of blockchain. This hinders erasing erroneous data, thereby making data entry in the blockchain system irreversible (Frauenfelder 2020). For example, consider a farmer who reports that he has used a specific type of seed (non-GMO), and these data are entered in the blockchain network. Say in a hypothetical scenario, the data entered are incorrect and are already populated to the blockchains. Erasing the data would be an additional task and would contribute to increasing effort and time. Another area of concern is the private key of the node on blockchain getting corrupted or lost. This will make blockchain unusable (Kamble et al. 2019).

Further, the processing of transactions on the blockchain is limited by parameters like size and interval of the transaction block (Potts 2019), and the existing protocols have limited scalability.In addition to all the issues mentioned above, the implementation cost of blockchain remains very high, making it challenging to adopt.

Research potentials

Blockchain technology, if explored, has ample potential in a system where much data and assurance of data security is involved. There are several opportunities to examine the usage of blockchain technology beyond food safety in the supply chain and transparency and traceability for consumers (Galvez et al. 2018). For example, shared specifications across the food industry, information of potential suppliers with the rates and material availability, and information on the requirement of a commodity would reduce the spending on raw material and would faster the procurement process.

Several R&D centers conduct similar experiments and render data in isolation. Due to time and resource constraints, these centers cannot conduct many trials, and many times these researches do not give a conclusive result. If several such results are shared across centers under a secured environment, further, with the application of big data science, the creation of predictive models would be easier. These predictive models based on data generated from different centers would reduce the R&D cost in the food industry.

Integrating AI and Blockchain can improve virtually every industry be it food supply chain logistics, healthcare record sharing, media royalties, or financial Security.

In addition, the integration of AI in Blockchain can help build a reliable technology-enabled decision-making system that is robust and secure. While AI can mine through the enormous volume of the dataset and discover patterns (Chen et al. 2021), Blockchain will help remove fraudulent data sets. With Blockchain, one can verify Scenarios and patterns created by AI.

Conclusion

The benefits of using blockchain for food traceability are clear and distinct. The data stored by blockchain systems are irreversible and transparent to all the stakeholders, thus making it unique and provides credibility to the whole system. The information on the blockchain system will allow the companies to strengthen their relationship with current customers and attract new ones (EU Food Fraud Network 2018) by sharing processes and record-keeping (Babich and Hilary 2020).

We can reduce the risks of food fraud and data tampering. In addition, it will shorten transaction time and reduce the overall cost in the long run (by reducing the overheads and intermediary costs).

It holds many promises, but we have seen until now that it is still in the early stages of commercialization. This means that food companies with sophisticated, mature supply chain systems will not switch willingly to the blockchain where the implementation cost is unpredictable, and success is still not guaranteed. However, once integrated with emerging technologies, we are confident that blockchain can empower consumers to know all relevant information about the products they consume in just one click.

Appendix A

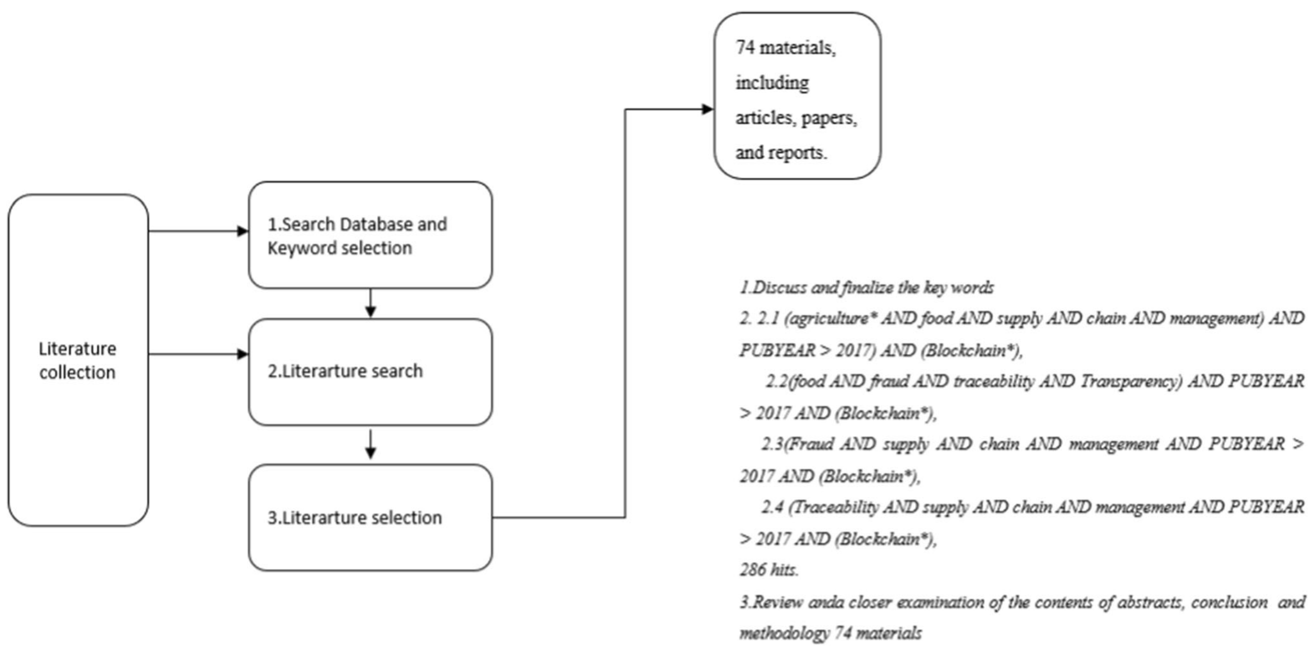


Figure: Approach taken for literature review.

Appendix B

Questionaries.

Which of the following you see as the key driver for the success of food industry in future?

1. Variants of the product
2. Going more natural
3. Right claim and transparency
4. Sustainable process and product
5. Healthy and personalized nutrition

Challenges in achieving the future goal

How you perceive following as the challenges for the future of food industry ?

Sematic differential (− 3 to + 3). − 3 as minor challenge, + 3 major challenge.

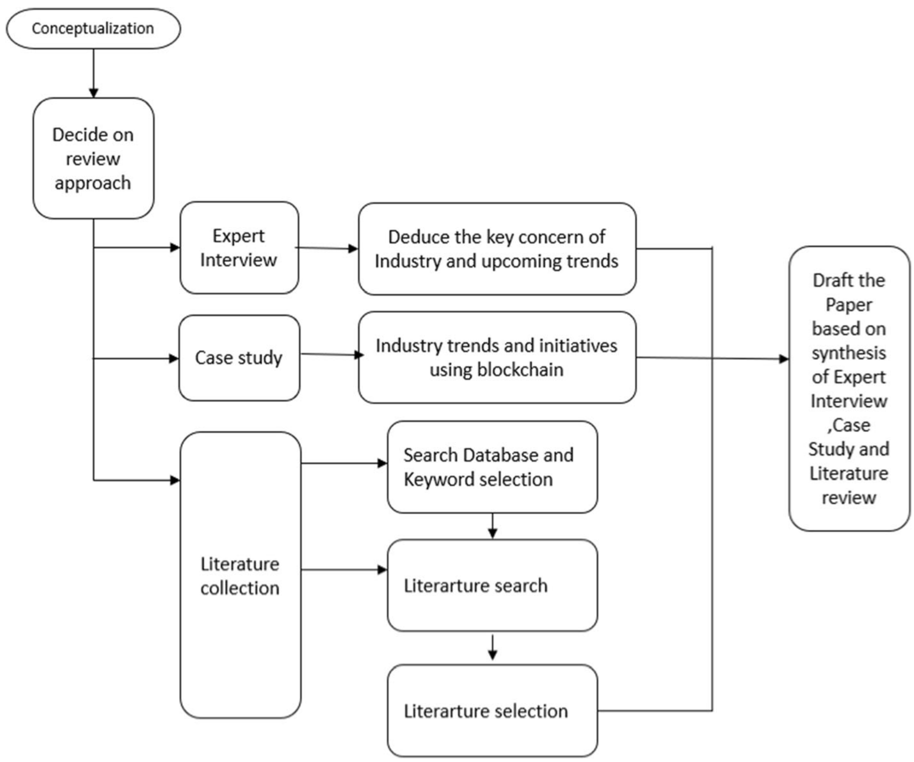
1. How do you think getting the right raw material as the challenge in future?
2. How do you see food frauds as the challenge for food industry?
3. How do you see building consumer trust as the challenge in future?

Screen capture of Questionaries and response recorded. We have numbered the expert to avoid revealing his personal identity.

	Respondents									
Future of Food Industry	1	2	3	4	5	6	7	8	9	10
Rating scale (1 to 5), 1 least important, 5 most important)										
Which of the following you see as the key driver for the success of food industry in future?										
1. Variants of the product	2	1	2	2	2	2	3	1	4	2
2. Going more natural	3	2	3	3	3	2	3	4	4	4
3. Right claim and transparency	3	4	3	3	3	3	4	4	4	4
4. Sustainable process and product	3	3	3	3	3	3	3	4	4	4
5. Healthy and personalized nutrition	2	2	2	3	3	3	4	4	3	3
Challenges in achieving the future goal										
How you perceive following as the challenges for the future of food industry ?										
Sematic differential (-3 to +3). -3 as minor challenge, +3 major challenge										
1. How do you think getting the right raw material as the challenge in future?	-3	3	-3	-3	-3	3	3	3	3	-3
2. How do you see food frauds as the challenge for food industry?	3	3	-3	3	3	3	3	3	3	3
3. How do you see building consumer trust as the challenge in future?	-3	3	-3	3	3	3	3	3	3	3

Screen capture of response of some of the experts.

Appendix C



Flowchart showing the approach taken for the review process

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Declarations

Conflict of interest We here by declare that the work described has not been published before in any form and it is not under consideration for publication elsewhere, its submission to JFST publication has been approved by all authors as well as the responsible authorities—tacitly or explicitly—at the institute where the work has been carried out. If accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder, and JFST will not be held legally responsible should there be any claims for compensation or dispute on authorship.

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